

Wind Energy

**Wind Energy**  
Grid Compatibility and Reliability  
of Wind Energy Systems

||| SCHAFFNER





## Schaffner Group

The Schaffner Group is the international leader in development and production of solutions which ensure efficient and reliable operation of electronic systems. The Group's broad range of product and services includes EMC/EMI components, harmonic filters and magnetic components as well as development and implementation of customized solutions. Schaffner components are deployed in energy-efficient drive systems and electronic motor controls, in wind and photovoltaic systems, rail technology, machine tools and robotics as well as power supplies for numerous electronic devices in sectors such as medical technology or telecommunications. Schaffner provides on-site service to customers around the world through an efficient, global organization and makes ongoing investments in research, development, production and sales to systematically expand its position as leader on the international market.

### A global one-stop shop

#### EMC/EMI filters

- PCB filters
- IEC inlet filters / Power entry modules
- DC filters
- Single-phase filters
- Three-phase filters
- Three-phase + neutral line filters
- Open frame filters

#### EMC/EMI chokes

#### Feedthrough filters and capacitors

#### Automotive components

#### Customized solutions

### Power Quality products

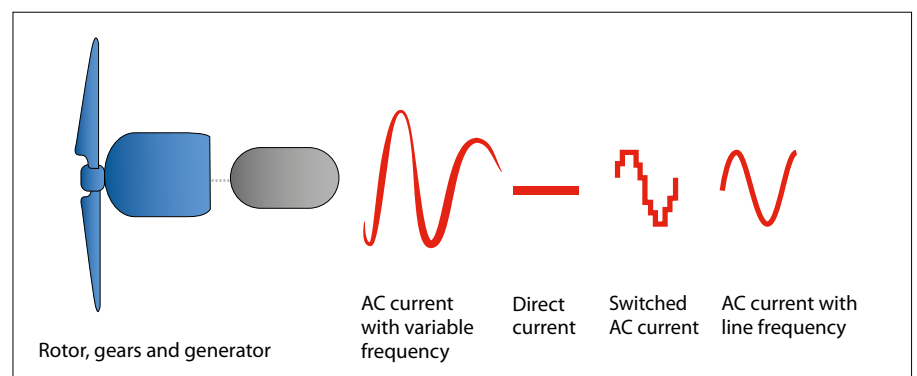
- Line reactors
- dv/dt reactors and filters
- Sine wave filters
- Harmonic filters
- Regen reactors and filters
- Transformers

### Customized solutions

## Electrical energy from wind power systems

Poul la Cour (1846–1908) was a Danish meteorologist and is considered to be the father of modern wind power systems for electricity generation. In 1891, he built the world's first wind power system for generating electricity. In la Cour's day, large cities were already supplied with electricity, while people in the countryside hardly had access to electricity. His greatest goal was to provide them this access. He considered electricity one of the most important technologies of the future that could simplify work and extend life's activities, such as learning, into the long, dark winter nights. And so he researched ways to improve the efficiency of windmills and use them to convert wind energy into electrical energy. La Cour was also one of the pioneers of modern aerodynamics and had his own wind tunnel to conduct his experiments. Source: Wikipedia.

Today, wind energy is globally considered to be one of the technologies of the future. And so, more and more large wind parks are being built on land and sea. Improving efficiency and reliability in the conversion of wind energy into electrical energy are technological challenges that are still being worked on today.



### 1: Energy conversion

The changing wind speeds, which influence the generator from the rotor, must be converted into stable AC current with a constant frequency. Modern wind power systems are nowadays operated with variable rotor speed. A frequency converter adapts the variable frequencies and voltages of the generator to the required network frequency of 50 Hz (60 Hz), phase angle and voltage. National and international regulations govern the reliability and quality of the AC current and voltage supplied to the network. The distribution of active and reactive power (default of  $\cos\phi$ ) and the conditions under which the system must support the network or may shut it down, are all regulated. The same applies to the harmonic content of voltage and current. If wind energy systems had to fulfil network connection requirements (grid code), they could make an important contribution to the renewable energy mix and ensure a reliable energy supply.

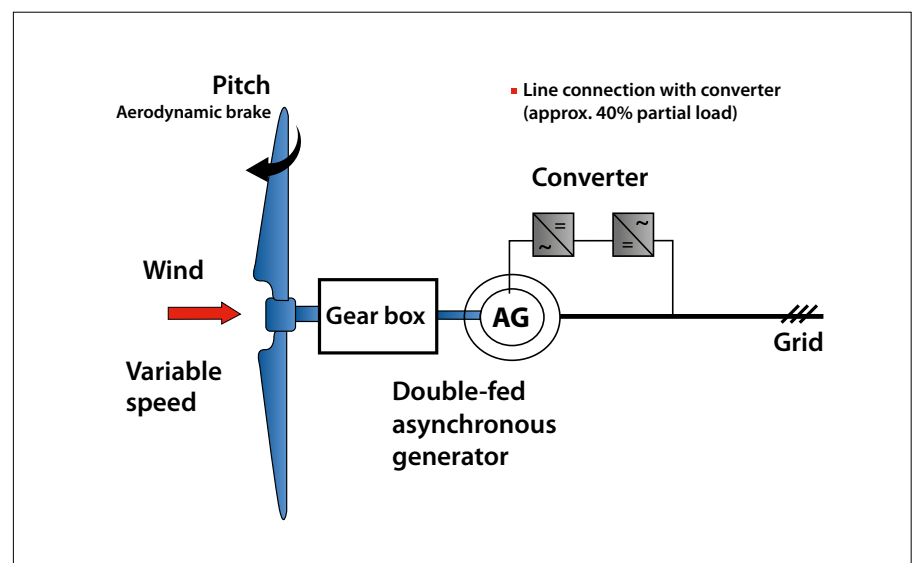
## Technology of modern wind energy systems

Whereas wind energy systems used at the turn of the millennium could only produce 1,000 KW, 50% of the systems used in many countries today have a capacity of 3 MW. Existing smaller systems are currently being replaced by large systems of up to 3.6 MW under the “repowering” concept.

To improve profitability, power plants used in offshore locations offer a high capacity of 5–6 MW and, considering their location on the high seas, they must also provide a high level of reliability while requiring low maintenance. The current largest wind energy system has a power output of 7.5 MW and a rotor diameter of 127 metres. Systems up to 12 MW are already in development.

There are two main generator concepts available in today’s markets: wind energy systems with either double-fed asynchronous generators or with synchronous generators. Both are based on variable-speed generators and use blade angle adjustment (pitch control) as power limiters.

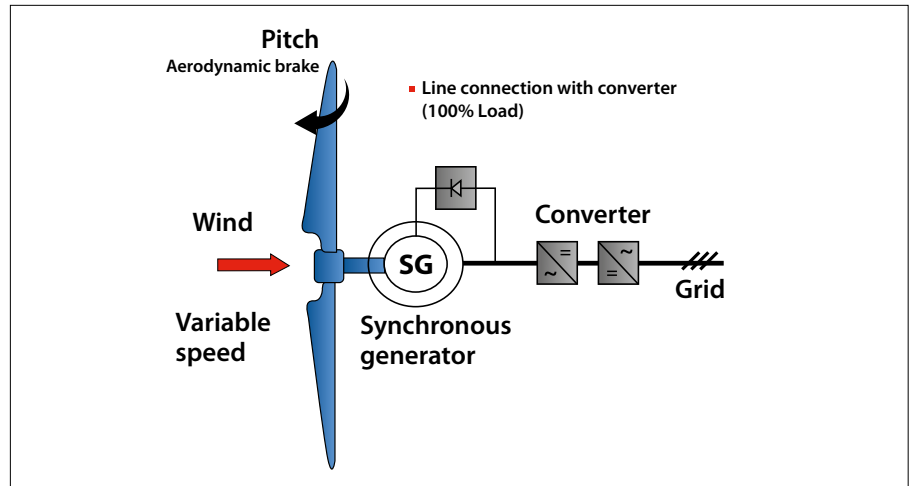
### Systems with double-fed asynchronous generator



2: Principle of double-fed asynchronous generator

The variable speed rotor drives a double-fed asynchronous generator via a gear box. Energy is controlled through adjustment of the rotor blades (pitch control). The generator rotor is connected to the network through a frequency converter, which permits both an over-synchronous and undersynchronous operation compared to the line frequency. As a result, the generator is variable speed. Only part (approx. 30–40%) of the output power or current has to be adapted to the desired line frequency through the converter.

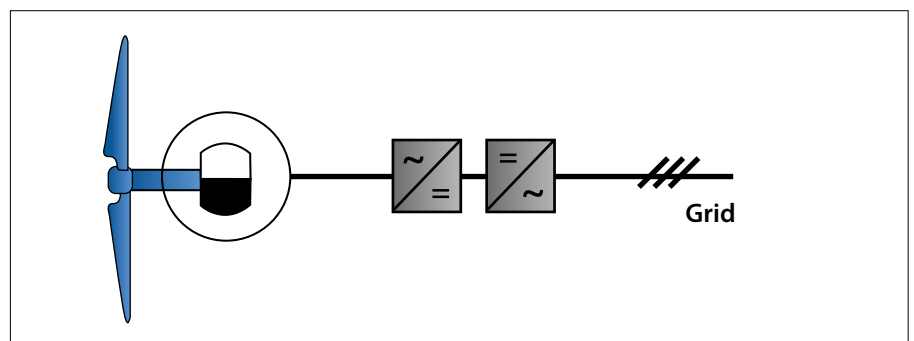
### Systems with separately excited synchronous generator (“full conversion”)



3: Principle of separately excited synchronous generator

Through the variable rotor speed, wind energy systems with synchronous generators can adapt themselves optimally to changing wind speeds and thus achieve a high degree of efficiency. Even here, too, power control is achieved by adjusting the blade angle (pitch control). The synchronous generator converts mechanical energy into electrical energy from variable rotation speed and thus frequency. The full generator output must be adapted via a frequency converter to the desired voltage and line frequency.

### Permanently excited synchronous generator (“full conversion”)



4: Principle of permanently excited synchronous generator

Permanently excited synchronous generators achieve a higher efficiency in the partial load operational range. Gearless systems are equipped with slow-running generators that have a higher number of poles. In this case, the design of the frequency converter is particularly demanding. Since efficiency optimization and component reduction are at the forefront when it comes to offshore systems, the wind energy systems tend to be gearless and with full power converters.

### Blade pitch control



5: Blade pitch control

The blade pitch control rotates the rotor blades out of the wind to prevent excess power output with rising winds. Depending on the measured electrical output, the rotor blades are rotated around their longitudinal axis, which reduces the wind energy absorbed. If the wind speed is still too high when the rotation of the rotor blades is at a maximum, the wind energy system is braked and taken off the network.

Servo motors with servo controllers are used for pitch control.





## Technology Trends

### I High Power

A clear trend in technical development is toward an ever higher power output of wind energy systems. For example, the average output of newly installed systems in 2001 was about 1,300 kW and in 2012 it had already risen to 3,000 kW. The effect of repowering and the increasing demand in the offshore area is clearly visible.

### I Reliability and profitability

A further trend is toward gearless wind energy systems with synchronous generators. These systems promise around 5% higher efficiency. The goal for the development of new wind turbines is to reduce complexity while simultaneously increasing reliability and profitability. The advantages of a simple design reflect in a reduced need of maintenance and repairs, as well as lower costs during manufacturing and power generation.

### I Innovative cooling concepts

With rising temperatures at the generator coils and magnets, the degree of efficiency and life span of the components decreases. Active liquid cooling reduces the generator mass significantly. Even the power electronics of the converters and their magnetic components, such as filter chokes, are connected to the water cooling circuit.

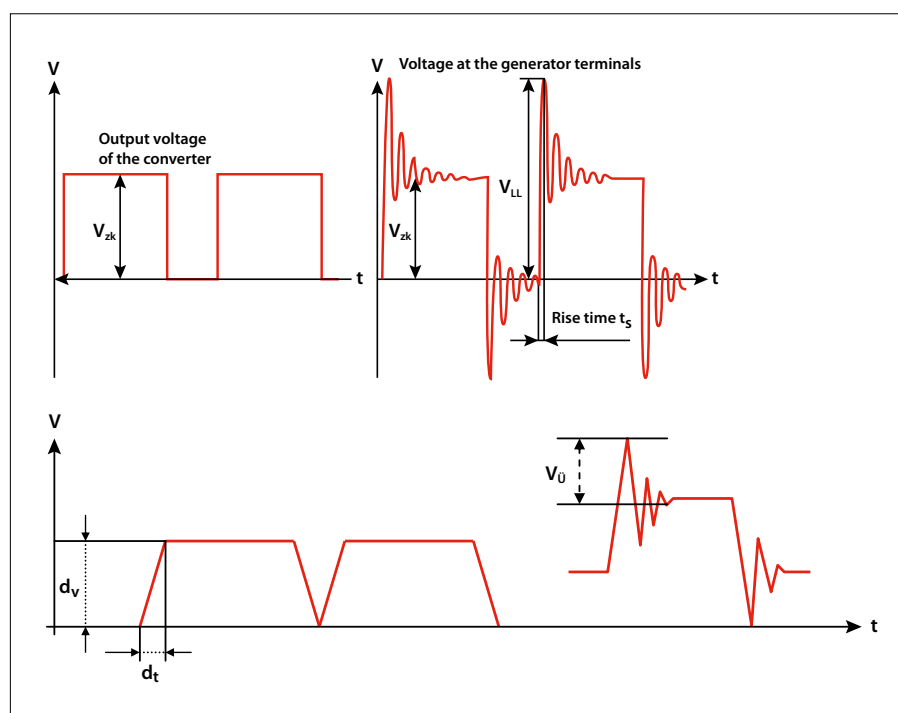




## Technical challenges

### Insulation damage to the generator windings

The coils of wind generators are subjected to various stresses. Therefore special requirements concerning the life span of the insulation system must be taken into account. The coils are usually designed for 690 V nominal voltage. However, due to high overvoltage peaks and high  $dv/dt$  levels, the coil insulation is overloaded with much higher voltage stress.



6:  $dv/dt$  at the generator coils

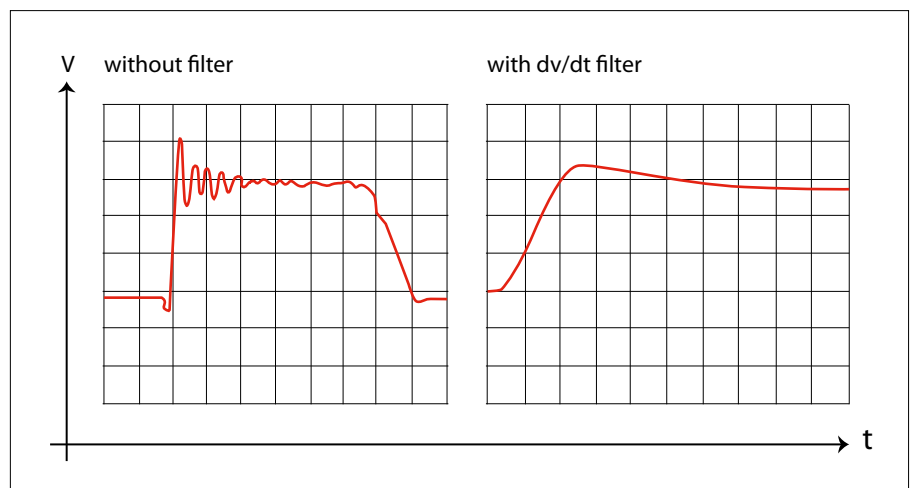
The problem is caused by the rise time and the fast repetition of the switching impulses of frequency converters. The voltage pulses generated by the converter run as travelling waves through the connection cable between converter and generator, which are reflected at the coils, resulting in overvoltage peaks at the generator coils. This generates voltage spikes with twice the level of the DC link voltage; at times exceeding 1100 V at 690 V nominal voltage. In practice, besides the peak value of the voltages phase to phase and phase to earth, even the  $dv/dt$  level plays a significant role. With  $dv/dt$  levels of up to 6 kV/ $\mu$ s, the resulting partial discharges age the insulation prematurely. As a consequence, expensive service calls and repairs, often in remote locations, are required.

### Bearing damage caused by bearing current

The use of fast switching IGBT converters can result in excessive bearing current, causing bearing damage to the high-power generators of wind power systems. Converters generate operational asymmetrical voltages to the earth potential, which can cause high bearing currents, depending on the voltage slew rate ( $dv/dt$ ). Another phenomenon in the case of operation with frequency converters is the occurrence of low-frequency circular current. An asymmetrical current distribution along the electrical machine causes a magnetic field, which generates pulse voltages in the generator shaft. Due to the low resistance of the shaft, high circulating currents flow through both bearings.

### Required measures

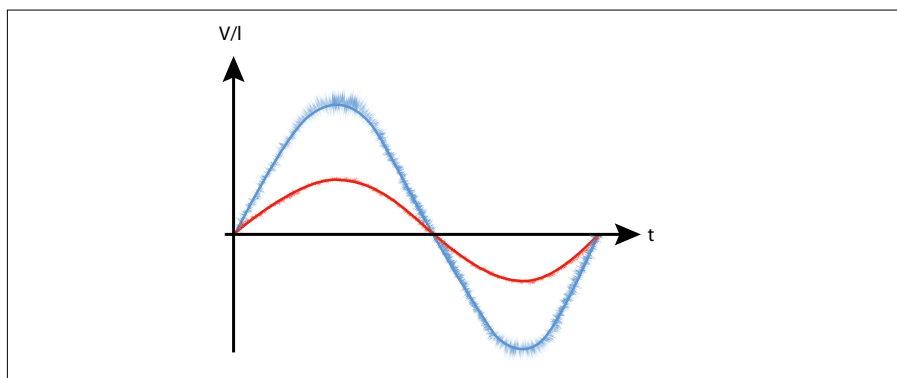
Several measures are required to avoid insulation damage and bearing current. The bearings used in generators should be insulated. Bridging of the bearings with slip rings is another possible method. All earth- and cable screening connections must be wired as short as possible and with low impedance for high frequencies. In addition, a  $dv/dt$  filter has to be installed to reduce the voltage rise time, avoid bearing damage and simultaneously protect the generator windings from excessively high voltage peaks.



7: Effect of  $dv/dt$  filters.

### Mains connection

Due to the low harmonics, pulse-modulated frequency converters with an intermediate DC circuit can be used for feeding into the grid. The converters, "active front end" (AFE) or "active infeed converter" (AIC), work with sine modulation and generate a nearly continuous frequency spectrum.



8: Interference voltage and current of the pulse frequency

These converters also feed high frequency currents into the grid, as can be seen in Picture 8. These ripple currents are caused by the switching frequency and its harmonics. This high-frequency current generates corresponding interference voltages within the grid, which spread through the medium voltage system and result in significant malfunctions of electric consumers. Due to the comparably high frequency, it generates additional zero crossings in the network voltage and can lead to thyristor malfunctions in rectifier systems. The permissible limits of high frequency current are defined by IEC 61400-21:2008. Even here, one is to refer to the EMC standard IEC 61800-3.

**IEC 61400-21:2008** Measurement and assessment of power quality characteristics of grid connected wind turbines.

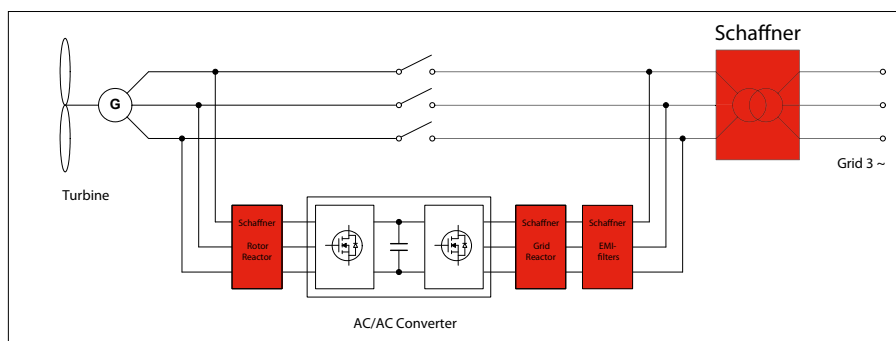
**IEC 61800-3** Adjustable speed electrical power drive systems – part 3 EMC requirements and specific test methods.

In determining the limit values, it should be taken into account that the standards for measurement of the inter-harmonics require different bandwidths of measurement frequency. Up to the fortieth harmonic, measurements are made with a bandwidth of 5 Hz, and in the range from 2 kHz to 9 kHz with a bandwidth of 200 Hz. The definition of the allowed high frequency ripple current results in limitation of the generated distortion voltage to 0.1% of the mains voltage in the frequency range up to 2 kHz and to 0.3% of the mains voltage in higher frequency ranges.

## Measures for grid compatibility – optimally integrated

Schaffner understands that the cost-effectiveness of wind energy substantially depends on the ability to optimize system components in terms of size and weight. This allows for smaller nacelles and lighter tower structures – which reduce total system costs. Based on its many years of experience in renewable energy and other demanding applications, such as railway technology, Schaffner knows well that the quality and longevity of the components must never be compromised.

For decades, Schaffner engineers have worked intensely to reduce high and low frequency interference in power electronics, with particular emphasis placed on inverters for the wind and photovoltaic industry. Schaffner customers benefit from this experience through highly integrated solutions, such as water-cooled chokes, dv/dt filters in open design for optimal cabinet integration, or high performance EMC filters up to 2500 A/690 V.



9: Example of Schaffner components in a double-fed system

With its own production facilities, development centers and customer service and application centers in Europe, Asia and North America, Schaffner is always in close contact with customers' development and application centers. Besides the manufacturing of filters and magnetic devices, Schaffner also offers:

- Professional on-site engineering support
- Measurement services in the laboratory and at the customer's location
- Custom product design and development
- Integrated EMC and power quality solutions
- Worldwide production and logistics
- Many years of experience in the wind sector

On the following page, you will find a selection of products that are used in connection with converters in the wind industry. In addition to a comprehensive standard product program, Schaffner specializes in tailor-made solutions that fit optimally into the system.

## Products and solutions for efficient and reliable energy feed-in.

	Product	Application/Data
	<b>dv/dt filter</b> <ul style="list-style-type: none"> <li>▮ Protects the generator coils</li> <li>▮ Limits voltage peaks</li> <li>▮ Reduces bearing currents</li> </ul>	<b>Water-cooled dv/dt filter</b> <ul style="list-style-type: none"> <li>▮ Low voltage and medium voltage</li> <li>▮ Up to 6000 A</li> <li>▮ Compact design for system integration</li> </ul>
	<b>dv/dt choke</b> <ul style="list-style-type: none"> <li>▮ Protects the generator coils</li> <li>▮ Minimizes voltage edges</li> <li>▮ Reduces bearing currents</li> </ul>	<b>Water-cooled chokes</b> <ul style="list-style-type: none"> <li>▮ Low voltage and medium voltage</li> <li>▮ Up to 6000 A</li> <li>▮ Optimized for integrated installation</li> </ul>
	<b>LC filter</b> <ul style="list-style-type: none"> <li>▮ Protects the generator coils</li> <li>▮ Reduces bearing currents</li> <li>▮ Eliminates voltage peaks</li> <li>▮ Reduces harmonics of the pulse frequency</li> <li>▮ Grid connection</li> </ul>	<b>Sine wave filter</b> <ul style="list-style-type: none"> <li>▮ Low voltage and medium voltage</li> <li>▮ Up to 6000 A</li> <li>▮ UL certification (standard filters)</li> </ul>
	<b>LCL filter</b> <ul style="list-style-type: none"> <li>▮ Reduces harmonics of the pulse frequency</li> <li>▮ Prevents resonances</li> <li>▮ Compliance with grid codes</li> <li>▮ Grid connection</li> </ul>	<b>Sine wave filter</b> <ul style="list-style-type: none"> <li>▮ Low voltage and medium voltage</li> <li>▮ Up to 6000 A</li> <li>▮ Optimal system integration</li> <li>▮ Air- or water-cooled</li> </ul>
	<b>Transformer LC filter</b> <ul style="list-style-type: none"> <li>▮ Reduces harmonics of the pulse frequency</li> <li>▮ Prevents resonances</li> <li>▮ Compliance with grid codes</li> <li>▮ Grid connection</li> </ul>	<b>Sine wave filter</b> <ul style="list-style-type: none"> <li>▮ Low voltage and medium voltage</li> <li>▮ Up to 6000 A</li> <li>▮ Optimal system integration</li> <li>▮ Air- or water-cooled</li> </ul>
	<b>EMC Filter</b> <ul style="list-style-type: none"> <li>▮ Compliance with EMC regulations</li> <li>▮ Increased conducted immunity</li> </ul>	<b>Standard EMC filter</b> <ul style="list-style-type: none"> <li>▮ 3× 690V</li> <li>▮ Up to 2500 A</li> </ul> 

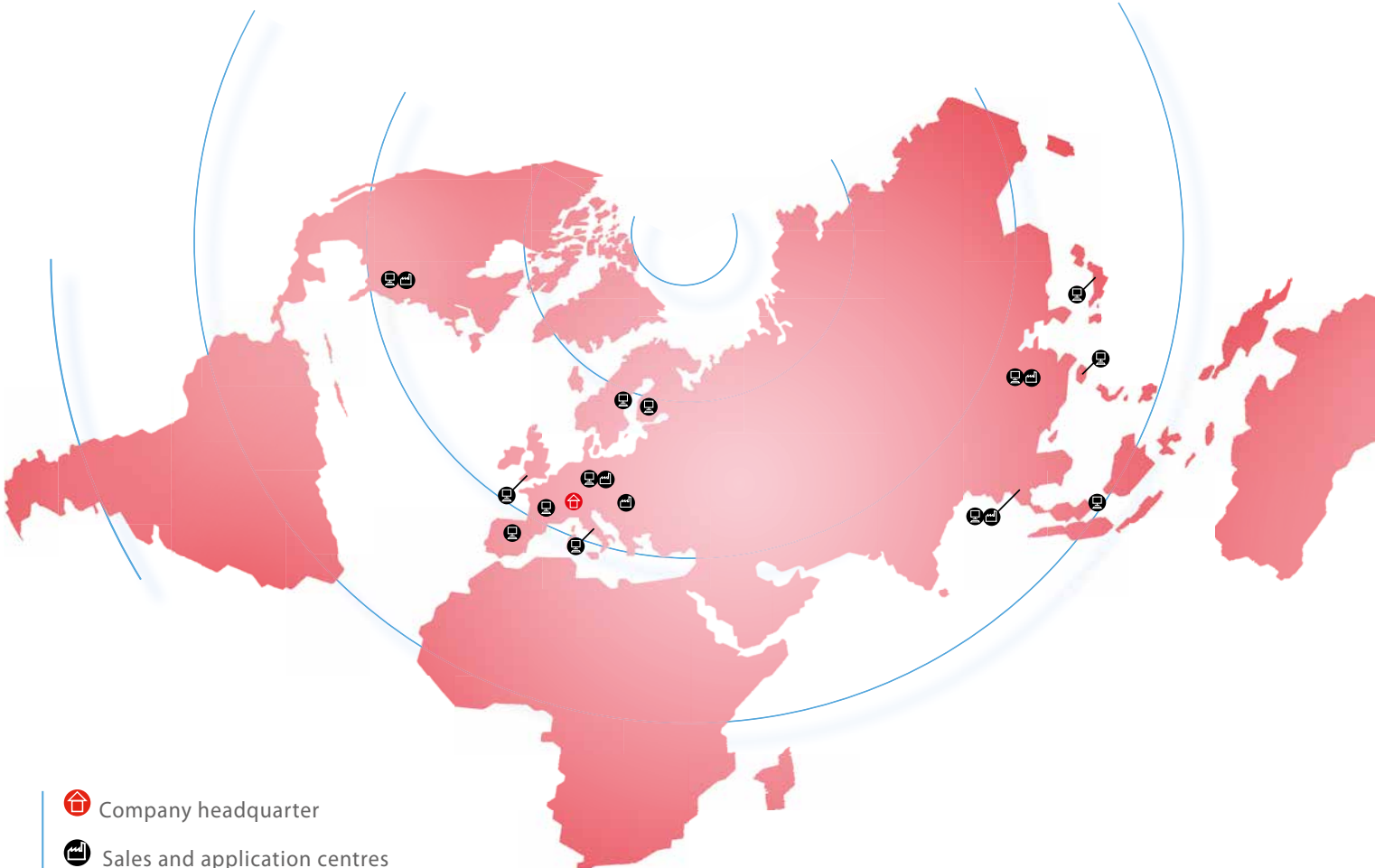





## Worldwide Presence, Global Experience, Unique Proximity to Customers

In addition to offering the most comprehensive range of EMC/EMI filters, Power Quality products, and magnetic components, Schaffner supports design and application engineers with engineering advice, testing, trouble-shooting, and custom product design.

With 16 customer service and application centers around the world, Schaffner is always close to the customer. Our own manufacturing plants in Germany, Hungary, Thailand, China and USA allow us to build both highly specialized parts as well as high volume commodities. Being the largest EMC/EMI filter manufacturer in the world, our global procurement network ensures the lowest raw material costs in times of soaring copper and steel prices, savings that we pass on to our customers.

Please feel free to contact your local Schaffner partner any time to discuss how we can support you in dealing with your individual challenges in the demanding wind turbine market.



-  Company headquarter
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